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FINITE ELEMENT ANALYSIS OF 1200CFM AND 600CFM GAS FILTER HOUSINGS

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The 1200cfm and 600cfm gas filter housings were investigated using finite element analysis techniques to examine if ASTM A554, Type 304 stainless steel (yield strength = 25,000 lb/in.^{2}) could be substituted for the currently specified AMS5563, Type 304 stainless steel (yield strength = 75,000 lb/in.^{2}). The factor of safety for the 1200cfm filter housing was determined to be 7.9 for the AMS5563 steel and 2.6 for the proposed ASTM A554 steel. The factor of safety for the 600cfm filter was determined to be 26.3 for the AMS5563 steel and 8.7 for the proposed ASTM A554 steel. The analysis results show that the fully loaded filter housings can be stacked at least two units high for the 1200cfm and 600cfm gas filters. The analysis results also show that the support arrangement does not affect the maximum stresses or deflections.

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PREFACE

The work described in this report was authorized under Project No. 10463884DC04, Collective Protection. This work was started in April 1996 and completed in May 1996.

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FINITE ELEMENT ANALYSIS OF 1200CFM AND 600CFM GAS FILTER HOUSINGS

1. Background

The 1200cfm and 600cfm Gas filter assemblies are about to go into initial production at the large filter production facility at Pine Bluff Arsenal. A physical description of the filter assemblies is given in Table 1 and a 1200cfm filter assembly with the side cover removed is shown in Figure 1. The current stainless steel material selected for the filter housing components is an expensive aerospace specification material, AMS5563, and a new less expensive ASTM stainless steel, ASTM A554, is being proposed for the production of the filter housing assemblies. The purpose of this analysis effort is to examine if there is any structural problems with this substitution. In order to obtain the required filtering capacity these filters are sometimes stacked on top of each other. It is important to know the structural response to this condition. There is also a need to know the filter housing's structural response to different support conditions. This analysis will examine these issues.

Nomenclature	NSN	Dimensions (in.)	Weight (lbs)
1200cfm Gas Filter Assembly	4240-00-312-2940	23.88x24x50.6	780
600cfm Gas Filter Assembly	4240-01-313-0721	23.88x24x28.1	433
120cfm Gas Filter Tray	4240-01-312-9146	23.5x22.33x3.5	55-60

Table 1: Physical Description

2. Method

The finite element analysis (FEA) of the 1200cfm and 600cfm gas filter housings was completed using commercially available FEA software. The filter housing consists of four different rectangular tubing types (Table 2) and a sheetmetal casing. The one and one-half inch by two inch tubing was used for the effluent end corner column. The one inch by two inch tubing was used in the remainder of the beams that make up the

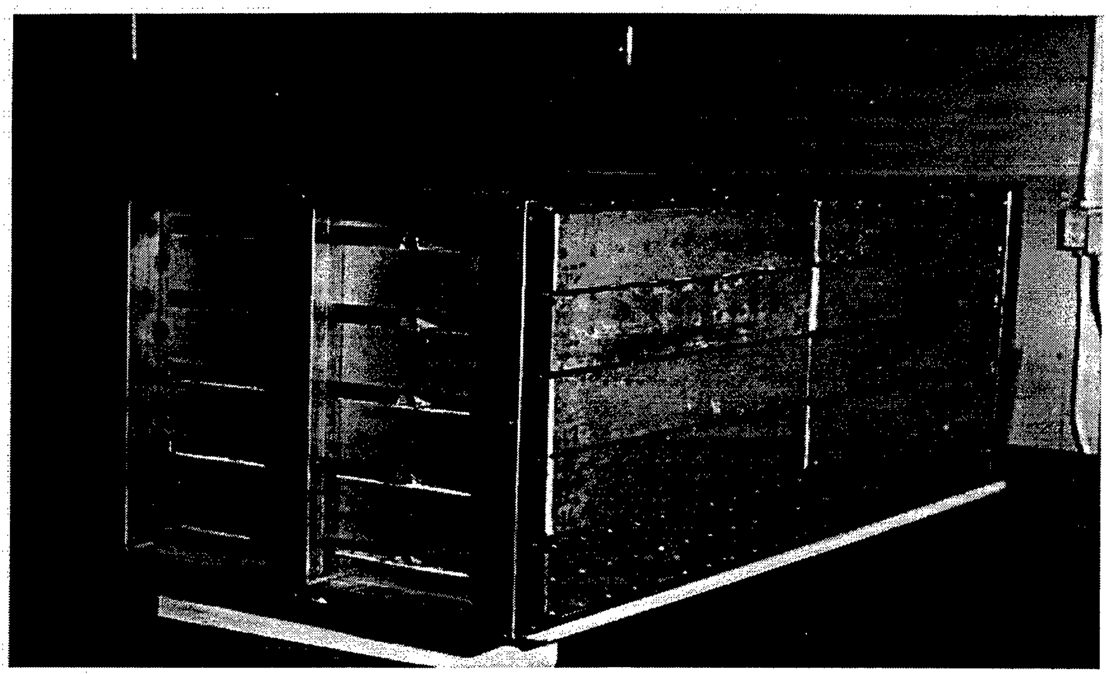

Figure 1: 1200cfm Filter Housing without Side Cover

end structures of the filter housing. The 7/8 inch square tubing was used in the top and bottom rails across the tray loading face and all the horizontal rails across the opposite face of the filter housing. The four middle rails across the tray loading face of the housing were made of the 5/8 inch square tubing.

AMS5563 304 Stainless Steel		
Width (in.)	Height (in.)	Wall Thickness (in.)
1	2	0.083
1.5	2	0.083
0.625	0.625	0.125
0.875	0.875	0.125
0.06 in. 304 sheet steel		
Yield Strength = 75 ksi		

Table 2: Current Material

The finite element model consisted of beam elements (Figure 2), BEAM4, to represent the different tubing sizes of the housing, and shell elements, SHELL63, to represent the outer sheetmetal casing (Figure 3). The dimensions used for the finite element geometry were the center lines of each beam. Each different tubing size was represented as a different set of real constants within the FEA software. Each set of real constants contained the moment of inertia, cross-sectional area, and dimension information (See Appendix A). A separate finite element model was created for each of the 1200cfm and 600cfm filter housings.

There were several assumptions made for this analysis.

1. The first is that the filter housing assemblies are not subject to any dynamic loading conditions, so a static steady-state analysis type was chosen.

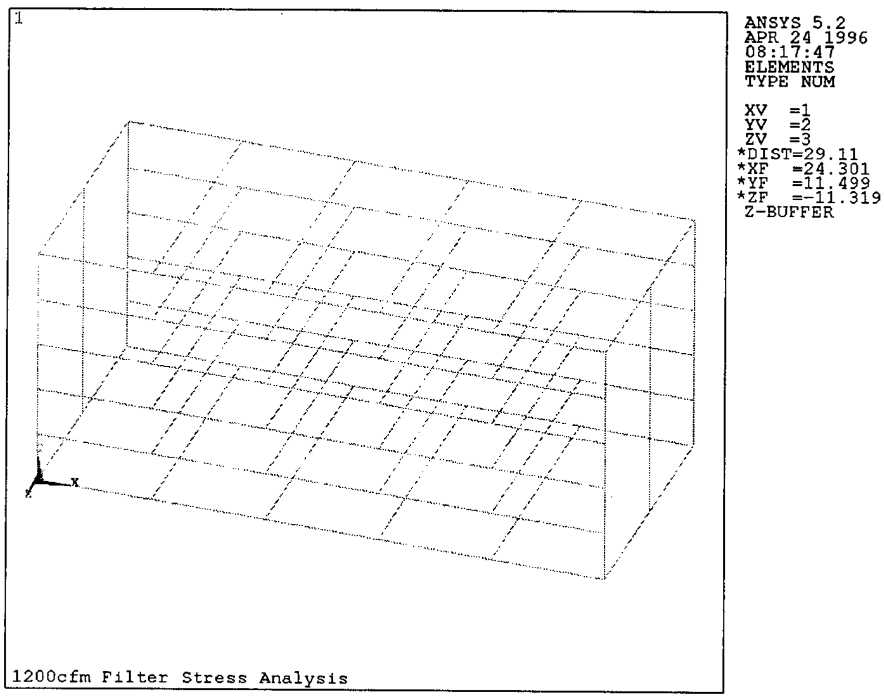

Figure 2: Beam Elements

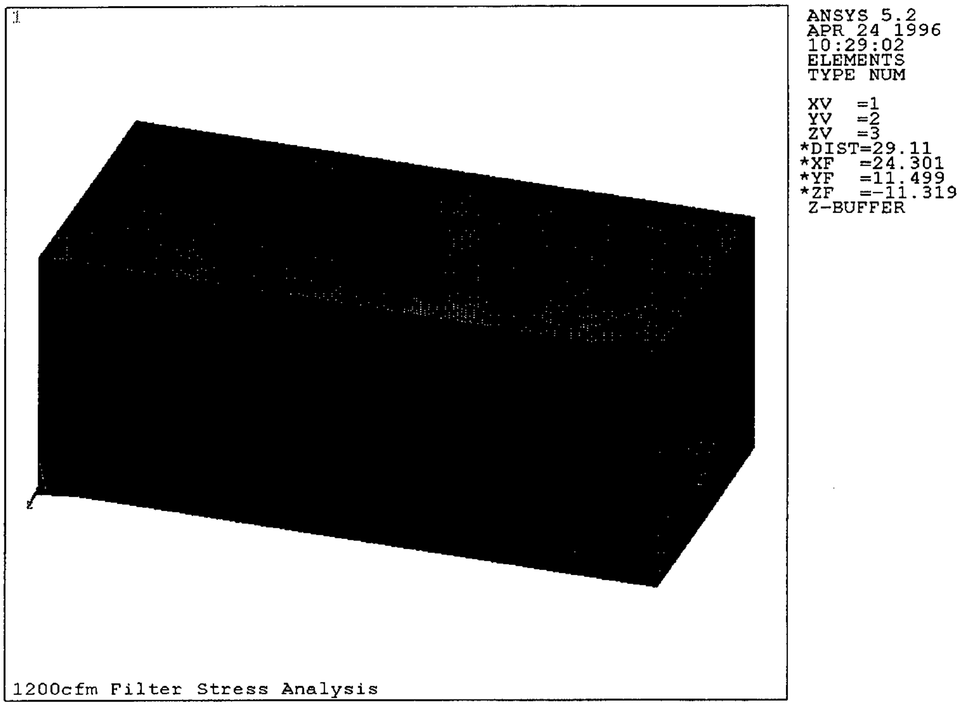

Figure 3: Shell Elements

2. The second assumption is that the result will be adequate to model the physical geometry by center lines only and to attach the shells to these center lines.

3. Also, the weight of the filter trays is assumed to be equally supported by the front and back rails.

4. It is assumed that the filters do not deflect into each other when installed. This implies that each shelf is only supported at the ends.

5. Finally, when the filter housings are stacked, the load is carried by the frame structure and not the top face.

These assumptions were made to reduce the complexity of the analysis thereby reducing the time and computer resources required without compromising the accuracy of the result.

2.1 Current Material Analysis

The first analysis ran was of the 1200cfm filter housing. The housing was subjected to three individual load cases. The first load case constrained the filter housing to be completely supported in the Y-direction along the bottom face of the filter housing. The load of the two filters on each shelf was calculated for and applied to the front and the back rails (Eqn. 1). Load case 1 is shown in Figure 4. The

$$P = \frac{\text{One-half Total Filter Tray Weight}}{\text{Rail Top Area}} \qquad (1)$$

$$P = \text{Applied Rail Pressure}$$

pressure on the top face of the 5/8 in. rails was 1.975 lb/in^2 and 1.411 lb/in^2 on the 7/8 in. rails. The outer shell elements have been omitted to allow the loads and constraints to be seen clearly.

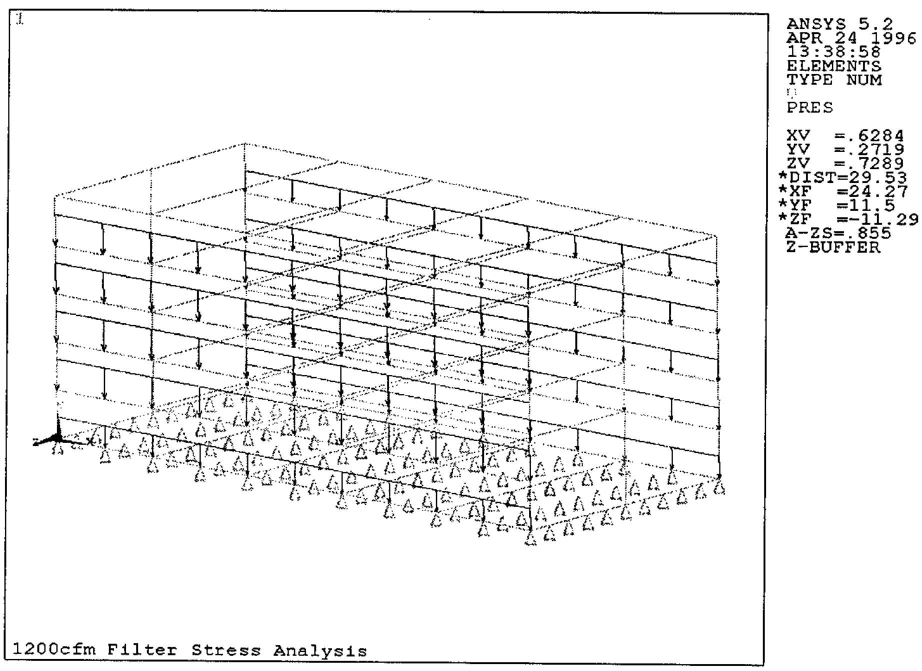

Figure 4: Load Case 1

The second load case used the same shelf loads as the first load case. The difference was in the constraint of the bottom of the filter housing. In this load case, the housing was supported only on the ends as shown in Figure 5. The purpose of this load case was to determine the response of the filter housing to this type of installation arrangement.

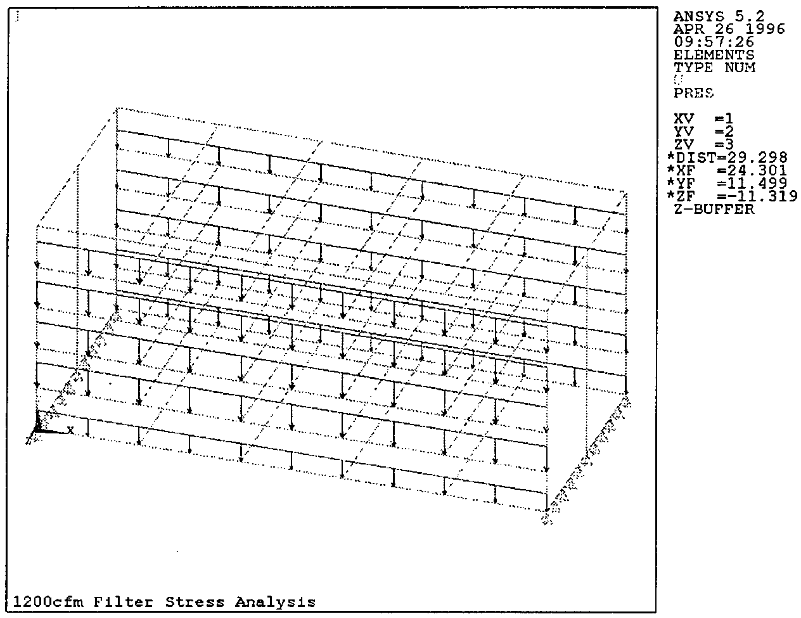

Figure 5: Load Case 2

The third load case continued to use the same shelf loads as the previous load cases and the same support constraints as the second load case (Figure 6). The third load case included a surface load along the top housing rails to simulate the stacking of one completely loaded filter housing on top. This pressure load was determined by dividing the total weight of filter housing assembly including trays by the top face area of the perimeter of the top shelf frame rails.

The second analysis run was of the 600cfm filter housing loaded with five filter trays with the existing material properties. The same three constraint conditions were used for these three load cases. The pressure loads were different due to differences in geometry. The pressure load on the shelves was determined by Eqn. 1. The pressure on the 5/8 in. rails was 1.835 lb/in^2 and 1.311 lb/in^2 on the 7/8 in. rails. For the third load case, the stacking load has changed. The stacking pressure applied to the top face of the perimeter

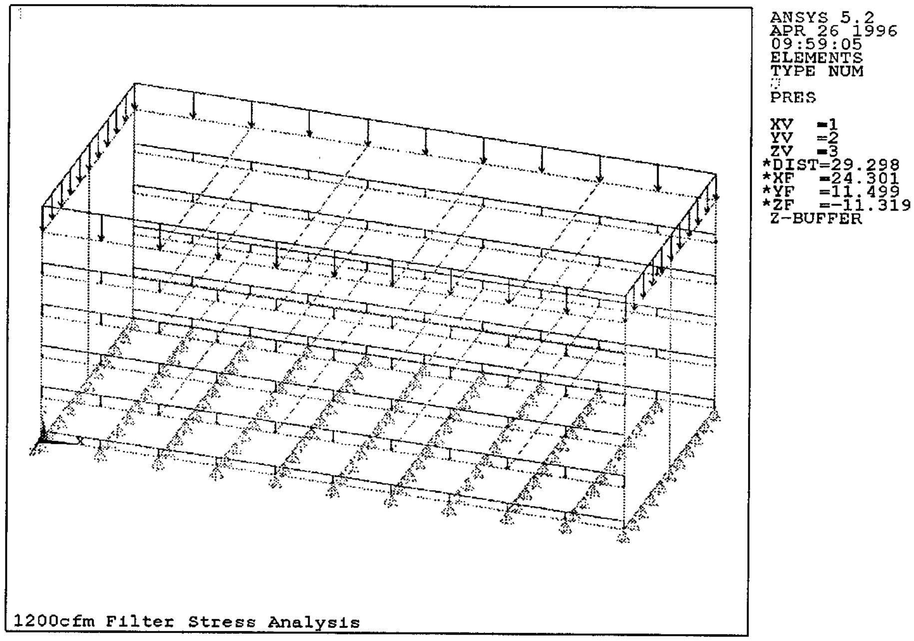

Figure 6: Load Case 3

rails was 7.54 lb/in^2 and used the same method as for the 1200cfm filter housing. Figure 7 shows the finite element model for the 600cfm filter housing under the conditions of load case 3.

2.2 Proposed Material Change Analysis

The next two analyses ran were repetitions of the 1200cfm and 600cfm analyses described previously, only with the proposed material properties. The material properties for the proposed material are shown in Table 2. The only differences between the materials is the wall thickness for the rectangular pieces and the yield strength. The differences in the dimensions were accounted for by changing the real constant data for the affected beams in the finite element model database.

A total of four analyses were ran. The 1200cfm filter housing with the current and proposed materials and the 600cfm filter housing with the current and proposed materials.

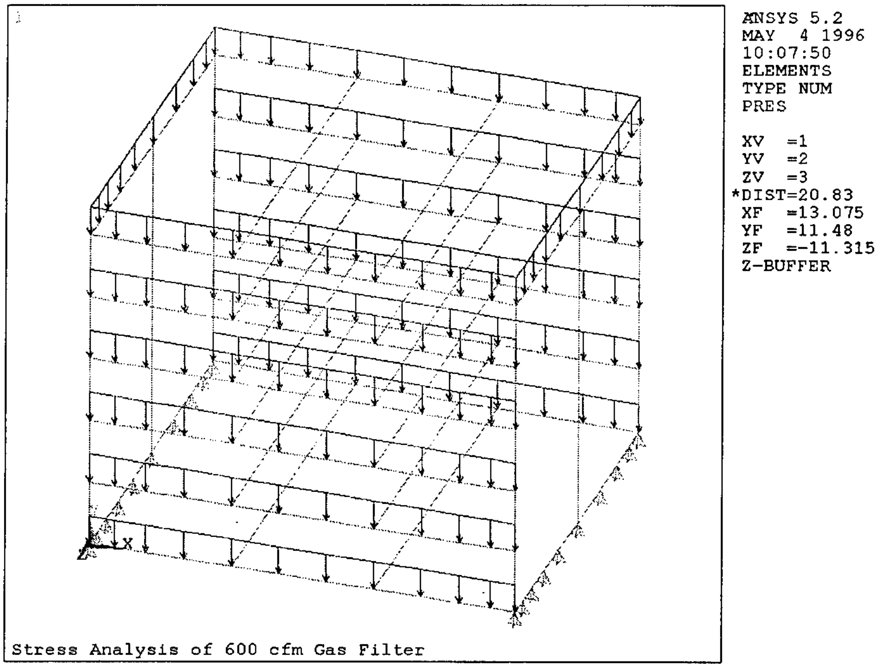

Figure 7: 600cfm Filter Housing, Load Case 3.

ASTM A554 304 Stainless Steel		
Width (in.)	Height (in.)	Wall Thickness (in.)
1	2	0.075
1.5	2	0.075
0.625	0.625	0.125
0.875	0.875	0.125
0.06 in. 304 sheet steel		
Yield Strength = 25 ksi		

Table 3: Proposed Material

3. Results

The results of the analyses give the stress and deflection data for both filter housings with trays in place and for each different load case. The first set of results is for the 1200cfm filter housing with the existing material. The first load case produced a maximum direct and bending stress of 9414 lb/in^2 in the second from the bottom 5/8-inch shelf at the influent end of the filter. A summary of the results for the first load case is shown in Table 4. The deflections listed are mid-span deflections and the listed stresses are located at the influent end of the shelves. The maximum stress in the sheetmetal shell is approximately 250 lb/in^2 for this load case.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	182	155	0	0
Second Shelf	9414	4060	0.072	0.025
Third Shelf	9383	4035	0.072	0.025
Fourth Shelf	9367	4024	0.072	0.025
Fifth Shelf	9344	3994	0.072	0.025
Top of Unit	34	34	0.5e-4	0.9e-5

Table 4: 1200cfm Filter Current Material for Load Case 1.

The second load case produced a maximum direct and bending stress of 9420 lb/in^2 in the second from the bottom 5/8 inch shelf at the influent end of the filter housing. A summary of the beam stresses and mid-span deflections is provided in Table 5. The maximum stress in the sheetmetal shell was approximately 411 lb/in^2.

The third load case for the 1200cfm filter produced a maximum direct and bending stress of 9439 lb/in^2 in the second from the bottom shelf at the influent end of the filter. A summary of the mid-span deflections and maximum stresses for each shelf is given in Table 6. The maximum stresses occurred in each shelf at the the influent end of the filter. The maximum stress in the sheetmetal shell was approximately 650 lb/in^2 for this load case.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	296	230	0.00015	0.00013
Second Shelf	9420	4064	0.072	0.025
Third Shelf	9377	4029	0.072	0.025
Fourth Shelf	9355	4015	0.072	0.025
Fifth Shelf	9329	3982	0.072	0.025
Top of Unit	58	53	0.00013	0.00012

Table 5: 1200cfm Filter Current Material for Load Case 2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	399	339	0.0003	0.00028
Second Shelf	9439	4078	0.072	0.025
Third Shelf	9384	4034	0.072	0.025
Fourth Shelf	9352	4014	0.072	0.025
Fifth Shelf	9321	3976	0.072	0.025
Top of Unit	191	182	0.0003	0.0003

Table 6: 1200cfm Filter Current Material for Load Case 3.

The next set of results was for the 600cfm filter housing with the original material. The first load case produced a maximum direct and bending stress of 2849 lb/in^2 in the second from the bottom shelf at the influent end of the filter. Table 7 provides a summary of the maximum stresses in each shelf and the mid-span deflections for each shelf. The maximum stress for each shelf occurred at the influent end of the shelf rails. The maximum stress in the sheetmetal shell was approximately 130 lb/in^2 for this load case.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	86	57	0	0
Second Shelf	2849	959	0.006	0.002
Third Shelf	2836	952	0.006	0.002
Fourth Shelf	2830	949	0.006	0.002
Fifth Shelf	2818	939	0.006	0.002
Top of Unit	3	1	0.0001	0.00001

Table 7: 600cfm Filter Current Material for Load Case 1.

The second load case for the 600cfm filter housing produced a maximum direct and bending stress of 2849 lb/in^2 in the second from the bottom shelf at the influent end of the filter housing. Table 8 provides a results summary of the maximum stresses and the mid-span deflections in each shelf. Again, the maximum stresses occurred at the influent end of the filter housing in each shelf. The maximum stress in the sheetmetal shell for this load case was approximately 300 lb/in^2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	86	57	0.00005	0.00004
Second Shelf	2849	959	0.006	0.002
Third Shelf	2836	952	0.006	0.002
Fourth Shelf	2830	949	0.006	0.002
Fifth Shelf	2818	939	0.006	0.002
Top of Unit	3	1	0.0001	0.00001

Table 8: 600cfm Filter Current Material for Load Case 2.

The final load case for the 600cfm filter housing produced a maximum stress of 2853 lb/in^2 in the second shelf at the influent end of the filter housing. Table 9 provides a results summary for this load case containing maximum stresses and mid-span deflections. The maximum stress in the sheet metal shell for this load case was approximately 450 lb/in^2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	375	349	0.0001	0.0001
Second Shelf	2853	962	0.006	0.002
Third Shelf	2838	951	0.006	0.002
Fourth Shelf	2838	953	0.006	0.002
Fifth Shelf	2825	947	0.006	0.002
Top of Unit	123	115	0.0001	0.0001

Table 9: 600cfm Filter Current Material for Load Case 3.

The next set of results is from the 1200cfm filter housing with the new material properties. The first load case produced a maximum stress of 9415 lb/in^2 in the second shelf at the influent end of the filter housing. Table 10 provides a summary of the maximum stresses and the mid-span deflections for each shelf for this load case. The maximum stress in the sheetmetal shell for this load case was 260 lb/in^2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	187	159	0	0
Second Shelf	9415	4059	0.072	0.025
Third Shelf	9383	4034	0.072	0.025
Fourth Shelf	9368	4023	0.072	0.025
Fifth Shelf	9344	3993	0.072	0.025
Top of Unit	40	39	0.00001	0.00001

Table 10: 1200cfm Filter New Material for Load Case 1.

The second load case produced a maximum stress of 9421 lb/in^2 in the second shelf at the influent end of the filter housing. Table 11 provides a results summary for this load case containing maximum stresses and mid-span deflections for each shelf. The maximum stress in the sheetmetal shell for this load case was approximately 440 lb/in^2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	305	236	0.0001	0.0001
Second Shelf	9421	4063	0.072	0.025
Third Shelf	9377	4028	0.072	0.025
Fourth Shelf	9356	4014	0.072	0.025
Fifth Shelf	9329	3981	0.072	0.025
Top of Unit	65	60	0.0001	0.0001

Table 11: 1200cfm Filter New Material for Load Case 2.

The final load case for the 1200cfm filter housing with the proposed material produced a maximum stress of 9440 lb/in^2 in the second shelf at the influent end of the filter. Table 12 provides a summary of the maximum stresses and mid-span deflections for each shelf in the housing. The maximum stress in the sheetmetal shell was approximately 700 lb/in^2 for this load case.

The final set of results is for the 600cfm filter housing with the proposed material properties. The first load case for this analysis produced a maximum stress of 2848 lb/in^2 in the second shelf at the influent end of the filter housing. The results are summarized for this load case in Table 13. The summary provides the maximum stress and mid-span deflection for each shelf in the housing. The maximum stress in the sheetmetal shell for this load case was approximately 135 lb/in^2.

The second load case of this analysis produced a maximum stress of 2843 lb/in^2 at the influent end of the filter in the second shelf. Table 14 provides a results summary for this load case containing the maximum stress and mid-span deflection for each shelf. The maximum stress in the sheetmetal shell was approximately 210 lb/in^2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	413	350	0.0003	0.0003
Second Shelf	9440	4077	0.072	0.025
Third Shelf	9384	4033	0.072	0.025
Fourth Shelf	9352	4013	0.072	0.025
Fifth Shelf	9321	3975	0.072	0.025
Top of Unit	198	188	0.0003	0.0003

Table 12: 1200cfm Filter New Material for Load Case 3.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	88	61	0	0
Second Shelf	2848	958	0.006	0.002
Third Shelf	2836	950	0.006	0.002
Fourth Shelf	2830	948	0.006	0.002
Fifth Shelf	2818	938	0.006	0.002
Top of Unit	4	6	0.00001	0.00001

Table 13: 600cfm Filter New Material for Load Case 1.

The final load case produced a maximum stress of 2852 lb/in^2 at the influent end of the filter in the second shelf. A results summary containing the maximum stress and mid-span deflections for each shelf is contained in Table 15. The maximum stress in the sheetmetal shell was 475 lb/in^2 for this load case.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	188	138	0.00005	0.00004
Second Shelf	2843	953	0.006	0.002
Third Shelf	2828	944	0.006	0.002
Fourth Shelf	2823	944	0.006	0.002
Fifth Shelf	2813	935	0.006	0.002
Top of Unit	18	15	0.00004	0.00003

Table 14: 600cfm Filter New Material for Load Case 2.

Results Summary				
	Maximum Stresses (lb/in^2)		Maximum Deflections (inches)	
	5/8in. Rails	7/8in. Rails	5/8in. Rails	7/8in. Rails
First Shelf	385	351	0.0001	0.0001
Second Shelf	2852	959	0.006	0.002
Third Shelf	2837	949	0.006	0.002
Fourth Shelf	2837	952	0.006	0.002
Fifth Shelf	2825	946	0.006	0.002
Top of Unit	119	109	0.0002	0.0002

Table 15: 600cfm Filter New Material for Load Case 3.

4. Discussion

The change in materials from the AMS5563 stainless steel to the ASTM A554 stainless steel will not compromise the structural integrity of the 1200cfm or 600cfm gas filter assemblies. The maximum stress in the 1200cfm filter occurred in the third load case with the new material with a magnitude of approximately 9440 lb/in^2. When this is compared to the yield strength of the two materials, the factor of safety for the AMS5563 material is 7.9 and for the ASTM A554 material it is 2.6. The material substitution poses no failure problems in the 1200cfm filter housing.

The maximum stress in the 600cfm filter housing was 2852 lb/in^2. This produces a factor of safety of 26.3 for the AMS5563 steel and 8.7 for the A554 steel. Again, the material substitution poses no failure problems in the 600cfm filter housing.

The results of load case 3 for each analysis show that the filter housings are strong enough to allow them to be stacked at least two units high. In examining the results from the filter housings, the maximum stresses or maximum deflections do not change significantly between load cases 1 and 2 and this load case.

The comparison of load case 1 to load case 2 for each analysis shows that the maximum deflection of the housings is not affected by the support conditions. The maximum deflection for the mid-span of the bottom shelf for load cases 2 and 3 is 0.0003 inches, which is negligible. The outer sheetmetal shell limits the deflection of the first shelf and the top of the unit to negligible values.

References

1. ANSYS Revision 5.2 software, ANSYS Inc., Canonsburg, PA 1995.

2. Singer, F.L., Pytel, A., Strength of Materials, 3rd ed., p. 808., Harper & Row, New York, NY, 1980.

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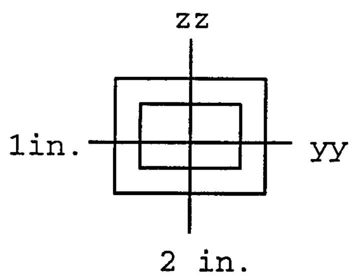
APPENDIX
Real Constant Data

Beam Data

1.) 1 in. x 2 in. x 0.083 in. wall



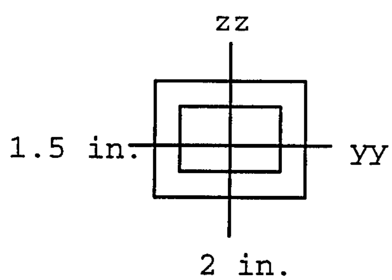
$$I = \frac{bh^3}{12}$$

I_{zz}= 0.2379 in^4
I_{yy}= 0.0780 in^4

A = 0.470 in^2

TKY = 2 in.
TKZ = 1 in.

2.) 1.5 in. x 2 in. x 0.083 in. wall thickness



A = 0.553 in^2

I_{zz}= 0.3142 in^4
I_{yy}= 0.1997 in^4

TKY = 2 in.
TKZ = 1.5 in.

3.) 0.625 in. square x 0.125 in. wall

A = 0.25 in^2 I_{yy} = I_{zz} = 0.0111 in^4

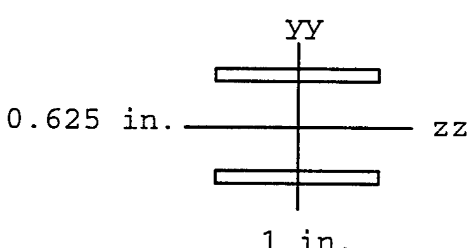
TKY = TKZ = 0.625 in

4.) 0.875 in. square x 0.125 in. wall thickness

A = 0.375 in^2 I_{yy} = I_{zz} = 0.0361 in4

TKY = TKZ = 0.875 in.

5.) 0.625 in. High Shelf Assembly with 0.06 in. Flanges



$$I = b\frac{H^3 - h^3}{12}$$

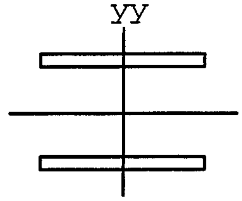
H = height
h = height - total flange thickness

A = 0.12 in^2

TKY = 0.625 in.
TKZ = 1 in.

I_{zz} = 0.0096 in^4
I_{yy} = 0.0100 in^4

6.) 0.875 in. High Shelf Assembly with 0.06 in. Flanges.



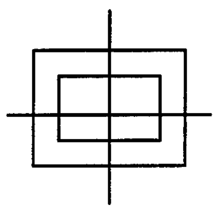
$$I = b\frac{H^3 - h^3}{12}$$

$A = 0.12\ in^2$

$I_{zz} = 0.0200\ in^4$
$I_{yy} = 0.0100\ in^4$

TKY = 0.875 in.
TKZ = 1 in.

7.) 1 in. x 2 in. x 0.075 in. wall thickness



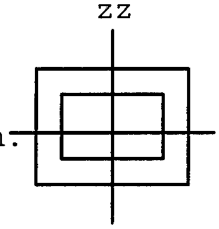
$$I = \frac{bh^3}{12}$$

$I_{zz} = 0.2182\ in^4$
$I_{yy} = 0.0720\ in^4$

$A = 0.428\ in^2$

TKY = 2 in.
TKZ = 1 in.

8.) 1.5 in. x 2 in. x 0.075 in. wall thickness.



$A = 0.5025\ in^2$

$I_{zz} = 0.2877\ in^4$
$I_{yy} = 0.1832\ in^4$

TKY = 2 in.
TKZ = 1.5 in.

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